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This report describes the implementation process of the Communications substrate of the Command Center Network, a local area network linking various processors in a Navy command center. Front-end processors are used to connect existing command center systems to the network; a gateway provides connectivity to the ARPANET, and a Network Services Manager provides network monitoring and control as well as centralized and/or specialized services.

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Bolt Beranek and Newman Inc.

Report No. 5053

Implementation of the Command Center Network: Final Report

K. Pogran

July 1982

Prepared for:
Department of the Navy
Naval Electronic Systems Command

IMPLEMENTATION OF THE COMMAND CENTER NETWORK:
FINAL REPORT

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July 1982

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1 INTRODUCTION

The Command Center Network (CCN) is an exploratory development program sponsored by the Naval Electronic Systems Command. The CCN provides a high-speed local area network to interconnect a variety of naval command center resources that previously have functioned as separate, distinct systems. With the interconnection of these systems, it becomes possible for the Navy to explore the establishment of standard, higher-level protocols to support exchange of information among diverse users whose systems incorporate varying interfaces and communication protocols.

Bolt Beranek and Newman Inc. (BBN) designed and implemented a "communications substrate" for the Command Center Network. This communications substrate consists of an adaptation of a commercially-available local area network product, LSI-11 "front-end" processors, LSI-11 Gateway and Terminal Interface Unit processors, and a UNIX-based Network Services Manager. BBN installed the communications substrate at the Naval Ocean Systems Center (NOSC) in San Diego, California, in June of 1981.

BBN's participation in the development of the Command Center Network was divided into two separate contracts: the <u>design</u> of the CCN communications substrate, and its <u>implementation</u>. This report is the final report for the CCN implementation contract, N00039-79-C-0482. For a complete picture of BBN's efforts in the design and implementation of the Command Center Network communications substrate, it should be read in conjunction with BBN Report 5046, "Design of the Command Center Network: Final Report." We recommend that the reader completely unfamiliar with the Command Center Network read BBN Report 5046 prior to reading this report.

A bibliography of all reports submitted under both CCN contracts may be found at the end of this report.

2 CCN IMPLEMENTATION EXPERIENCES

The CCN communications substrate design and implementation efforts at BBN were conducted essentially concurrently, resulting in considerable interaction between the two. Since implementation of various aspects of the CCN communications substrate was begun virtually as soon as preliminary specifications for them were complete, it was possible for early implementation experiences to provide feedback useful in developing the final specifications for the communications substrate. This was particularly helpful because the application of local area network technology was a relatively new and uncharted field in late 1979 when the CCN implementatioin effort was begun.

2.1 CHAOSNET As the Prototype CCN Local Network

Of course, proceeding with the implementation while the design effort was still in progress did lead to some false steps that later had to be retraced. The largest such "false step" was the implementation of the CHAOSNET hardware and software originally selected for the communications substrate in October 1979. As we described in BBN Report 5046, by spring of 1980 we realized that the Net/One system, soon to be available from Ungermann-Bass, Inc., would better meet the objectives of CCN. Because implementation of much of the CHAOSNET hardware and software was nearly complete, it was decided that the best course of action was to continue with the CHAOSNET development and to install it in the CCN Testbed at NOSC as a prototype system so that NOSC personnel could obtain early experience in developing applications software for the CCN front-end processors.

The decision not to use the CHAOSNET equipment for the final, installed, CCN communications substrate also removed the possibility that the Command Center Network would be dependent upon equipment that was not readily available and for which there was little engineering expertise. The decision to use the already-developed CHAOSNET hardware and software as a prototype system to aid software development turned the potential false step to advantage.

The CHAOSNET hardware is described in BBN Report 4311, "The Command Center Network: Preliminary Specification." Our experience in implementing it, based on designs provided by its developer, the MIT Artificial Intelligence Laboratory is related in BBN Report 5048, "Command Center Network: Semiannual Technical Report No. 1."

2.2 The Change to Net/One

The decision to convert from CHAOSNET equipment to Ungermann-Bass Net/One equipment was not made lightly because we had a considerable investment in the CHAOSNET hardware. However, it was clear that the advantages of using a commercially-supported product that met the basic communication needs of the CCN outweighed the schedule and cost advantages of continuing our commitment to the CHAOSNET. The advantages we perceived for the Net/One system, discussed in BBN Report 5046, were as follows:

1. The NOSC CCN configuration could be expanded readily by the purchase of additional Net/One units; additional CHAOSNET controllers and receivers would have had to be constructed specially, when required.

2. Ungermann-Bass would provide repair services for its Net/One hardware.

3. CCN would be able to take advantage of product improvements and new developments from Ungermann-Bass; lacking in-depth CHAOSNET expertise, we had no plans for continued CHAOSNET development.

4. Because it was commercially available, Net/One equipment could be procured easily for other Navy applications.

In addition, the plans for the CCN Network Services Manager (NSM) called for the construction of a direct, high-bandwidth interface device to connect the NSM host to the CCN local network. For the CHAOSNET, this would require the development of a CHAOSNET controller specifically designed to interface to the selected NSM host, the BBN Computer Corporation C/70 UNIX system. With Net/One we were able to use the Net/One Network Interface Unit (NIU) as a building block, and design an interface compatible with the NIU's I/O structure. This approach was more in keeping with the CCN objective of making maximum feasible use of available local network "building blocks" -- and was also considerably easier.

2.3 Implementing the LSI-11 Ungermann-Bass Parallel Interface

The switch from CHAOSNET to Net/One was slightly less satisfactory, from an implementation point of view, for the CCN LSI-11 front-end, gateway, and terminal interface unit processors, than it was for the NSM. The CHAOSNET controllers were UNIBUS peripheral devices (see BBN Report 5048); through the use of a QBUS-to-UNIBUS converter (we selected the Able Computer Technology "QNIVERTER"), the CHAOSNET controller could be connected to the CCN LSI-11's. No such "direct" LSI-11 interface existed for Net/One; we had the choice of either <u>developing</u>, ourselves, a direct interface to the Net/One Databus for the LSI-11, similar to the interface we designed for the C/70, or to <u>adapt</u> a standard Net/One interface for our use.

In this case, implementation considerations fed back to the design of the communications substrate: we concluded that the eight-bit parallel, programmed I/O interface offered for the Net/One NIU would provide adequate performance for an individual CCN LSI-11 processor, and that the development of a specialized interface for the LSI-11, roughly equal in complexity to the interface for the C/70, would therefore not be worthwhile. The parallel programmed I/O interface could readily be connected to the LSI-11 QBUS using a small amount of interface circuitry built upon a standard Digital Equipment Corporation (DEC) LSI-11 Interface Foundation Module, the DRV11-P. The interface constructed in this manner was named the "LSI-11 Ungermann-Bass Parallel Interface" (LUBPI).

Why the difference in approach between the C/70 and the LSI-11's? There were two reasons: <u>functionality</u> and <u>cost</u>. The CCN LSI-11's each served a single purpose; the front-end LSI-11's, in particular, each served a single command center applications host. The NSM C/70, on the other hand, provided services that were shared by the other hosts on the network. In addition, the Network Services Manager design included a monitoring capability that requires a particularly high-bandwidth path to the CCN local network. The Command Center Network had but one Network Services Manager; on the other hand, there was a multiplicity of LSI-11 systems. From a financial standpoint, a single copy of a complex interface is more affordable than several copies would be.

The "protocol" for use of the eight-bit parallel interface for the LSI-11's was devised with the aid of Ungermann-Bass, as the Net/One standard product did not make use of that interface at the time. In fact, the only standard interface to the Net/One NIU, at the time the product was first introduced, was the serial RS-232 interface, for which Ungermann-Bass provided only terminal-to-terminal port, "virtual circuit" service. Use of the parallel port was therefore an innovation for Ungermann-Bass as well as for us.

The parallel port protocol specified in BBN Report 4991, "Design of the Command Center Network: Final Hardware and Software Specifications," was developed in a very pragmatic way. The parallel port of the NIU was based on a Zilog Z80 parallel I/O (PIO) integrated circuit. The Z80 PIO permits several forms of communication, including use as a dual port with limited "hand-shaking" for data transfer, or as a single port with separate control and data bit signals. Because we wished to exchange interrupt information as well as data, we chose the mode that provided the single port with control signals.

With that decision made, we then faced the problem of connecting the parallel port, so configured, to the LSI-11. Here, we had somewhat less of a choice. The interface signals we could obtain from the Z80 PIO port were <u>almost</u> compatible with the interface signals from one standard DEC parallel interface module, the DRV11. However, "almost" did not permit a direct interconnection, and no other DEC parallel interface module came as close. The DRV11-P Interface Foundation Module, on the other hand, offered the opportunity for us to build a parallel interface to almost any interface specification necessary, with the LSI-11 QBUS logic handled by the circuitry of the DRV11-P. The interface we required was, of course, very close to the DRV11 specification; we were able to implement it on the DRV11-P by using only six integrated circuit packages. The LUBPI could be termed a "semi-custom" interface; from the point of view of designing, implementing, and constructing the required copies of the interface, it was a far better approach than to design either an LSI-11 interface or a Net/One interface from scratch.

2.4 The C/70 Network Services Manager Interface for Net/One

Because of the importance and nature of the role the C/70 Network Services Manager plays in the Command Center Network, the C/70 must be attached to the Net/One local network system via a direct, high-bandwidth interface. While the architecture of the interface device, called the "MBB Ungermann-Bass Interface" (MUBI), was determined by the relationship between the I/O architecture of the Ungermann-Bass Net/One processor and the C/70 I/O bus, its physical form was strongly influenced by implementation considerations. Two primary facts dictated the shape taken by the MUBI:

1. The C/70 I/O bus could be extended, via a set of three 100-conductor flat ribbon cables, to a length of six to ten feet.

2. The Net/One Network Interface Unit Databus was designed specifically to be internal to the Net/One NIU.

Clearly, the only configuration possible was one that placed the MUBI inside the Net/One NIU enclosure, powered from the NIU and cabled to the C/70. This is the form the MUBI took.

Our experiences in implementing the MUBI hardware and software are described in BBN Report 5050, "Command Center Network: Semiannual Technical Report No. 3."

2.5 LSI-11 System Software

The LSI-11 system software we used in the CCN project was, for the most part, obtained from other sources, then adapted and integrated with software written specifically for CCN. The version of the MOS operating system we used was derived from the SRI International MOS system, and was used in several DARPA-sponsored networking projects at BBN. The TCP, IP, and TIU implementations were obtained from the same source.

The local network device driver software for both CHAOSNET and Net/One was, of course, developed specifically for CCN. In addition, the CCN-ARPANET gateway code was written specifically for CCN, as there was no suitable "standard" Internet LSI-11 gateway at the time the CCN-ARPANET gateway was developed.

2.6 LSI-11 Applications Software Experiences

In CCN, the term "applications software" refers to software written for the LSI-11 front-end systems that deals with the interface to the attached command center applications processor. Written by NOSC personnel, and integrated with the BBN-provided LSI-11 systems software as part of the CCN installation effort, this software varied in size, complexity, and functionality from application to application. The most complex front-end applications software, the NAVMACS message processor server, was a particularly "tight fit" within the 28 Kword memory of the CCN LSI-11's. The ability to fit this software into the CCN front-end, along with the MOS operating system, the Net/One device driver, and TCP/IP process, required a tradeoff that involved reducing the size and number of TCP/IP packet buffers in the front-end; this, in turn, had a direct bearing on the performance of the CCN NAVMACS application.

The conclusion to be drawn from this experience is that the 28 Kword LSI-11's are not well suited to a role in the CCN that involves a considerable amount of applications software in the front-end processor. Unfortunately, conversion to the LSI-11/23, with extended memory capabilities, is not a reasonable solution, as MOS relies extensively on single-word pointers and cannot take advantage of the extended memory. There is, therefore, no short-term solution to this problem. There are, however, two possible long-range solutions:

1. Move most of the application processing to another CCN node, leaving little functionality beyond mediation between the application processor interface and TCP, in the front-end. The Network Services Manager would be a suitable node for processing that does not have a strict real-time requirement. There is no node in the current CCN configuration that can handle real-time processing in this manner. Such a node, which we call a "Network Traffic Processor," should provide:

   a. a small, real-time operating system (similar to MOS),

   b. 1/4 - 1/2 MByte of memory, and

   c. an I/O structure that can readily accommodate a high-bandwidth interface to the CCN local area network.

2. Replace the LSI-11 front-end processor with a microcomputer system based on a more modern and more capable microprocessor such as the Motorola 68000 (with attributes similar to those described in a. and b. of solution 1.) which could properly handle the traffic processing load.

Since the microcomputer systems proposed in the two solutions are in fact quite similar, the issue really comes down to the question:

"Should traffic processing in CCN be performed in the front-end, or should the functionality of the front-end be limited to communication functions and the handling of the application processor interface?"

At present this question remains unanswered and it is an interesting topic for future study.

2.7 C/70 Network Services Manager Software

Software for the C/70 Network Services Manager is the one area in which the system delivered to NOSC for the CCN Testbed diverged from the specifications developed under the CCN design effort. This was due largely to schedule considerations: TCP, in particular, was not available for the C/70 UNIX system at the time it would have been required for the NSM. Therefore, the software provided for the CCN Testbed was implemented so as not to require TCP (for example, we provided an implementation of the "Trivial File Transfer Protocol" to effect file transfers between the ACCAT PDP-11/70 UNIX system and the C/70 NSM via the ARPANET and the CCN-ARPANET gateway).

In addition, as we described in BBN Report 5046, the initial decision made to adapt the NU network monitoring and control system software for use with CCN had to be rescinded when it became apparent that NU would not be completed in time, and, moreover, that the modifications required to NU would be sufficiently extensive that, to meet the CCN project schedule, an alternative course of action was preferable. This led to the development of the CCN Monitoring System software which is described in BBN Report 4991.

One particularly bright spot in the Network Services Manager software picture was the microcode and macrocode UNIX kernel device driver software developed for the MUBI. As described in BBN Report 5051, this software, in conjunction with the MUBI hardware, was demonstrated to provide a raw packet throughput rate of approximately 2 Mb/s, roughly half the aggregate bandwidth available on the Ungermann-Bass Net/One 4 Mb/s contention bus coaxial cable network. This successful experiment helped to validate the design philosophy of the software, described in BBN Report 5047, which was to provide a high-bandwidth path through the UNIX kernel between the MUBI hardware and user-level code.

3 OBSERVATIONS AND CONCLUSIONS

The Command Center Network implementation effort may be viewed on the one hand, as a validation of the network design and specifications developed during the CCN design effort, and on the other, as a laboratory experiment in the application of local area network technology to a practical problem. In fact, the CCN implementation effort was both of these; it produced an "exploratory development model" of the Command Center Network for use at the CCN Testbed at NOSC, and it provided an interesting set of experiences that, we hope, can guide others in applying local network technology.

Perhaps the most significant conclusion to draw specifically from the CCN implementation experience is that selecting and procuring the local area network technology to be used in an application such as CCN is, truly, the tip of the proverbial iceberg. This lesson has been learned in applying long-haul network technology; but it seems it must be learned again with local network technology. The trap is this: local network technology is, by its very nature, inexpensive when compared to long-haul network technology. Indeed, it is this property of local network technology that makes it possible to contemplate local networks with hosts that are microcomputer systems, concentrators for small numbers of terminals, etc. We therefore <u>want</u> to believe that the software required for local area networks should be similarly "inexpensive" and less complex than the software needed for applications of long-haul networking. Experience shows that it is not. There are a number reasons for this and we present two that we feel are particularly important:

1. Local area networks rarely stand alone. While one might contemplate the use of simplified protocols that take advantage of the high throughput, low delay characteristics of local area networks, the need to intercommunicate with other networks on a regular basis argues against this approach.

2. The high bandwidth of local area networks can present problems to the host programmer. Buffer allocation strategies that may have sufficed when one was dealing with a 9.6 Kb/s serial line or a 100 Kb/s network attachment stand a good chance of failing when applied to a 10 Mb/s local area network.

With the second point above we do not mean to imply that the <u>entire</u> 10 Mb/s capacity of the local area network will necessarily be "aimed" at a single host for a long period of time (although this is conceptually possible, we believe it is a pathological case that need not be handled particularly well); however, in order to take advantage of the local area network, the host must be prepared to receive a sequence or burst of packets from the network in rapid succession. By way of analogy, if the problem of handling a long-haul network communications interface is viewed as drinking from a water fountain, the problem of interfacing to a local area network may be viewed as taking a drink from a firehose: the same commodity is being obtained, but there's something qualitatively different about the experience.

One final issue raised in the course of the implementation of the Command Center Network concerns the role of the CCN front-end processors, and where "traffic processing" can best be performed. We believe that this issue, discussed in section 2.6, is crucial to the long-term success of the CCN and should be addressed in any future work with the Command Center Network.

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